A Self-Calibration Antenna Array System with Moving

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Abstract **- In this paper, an antenna array system with self-calibration capability to the antenna element position errors is proposed. The essential concept of self-calibration is to detect the element positions by using near field reference sources. The estimated position information is further substituted into the beamforming process to correct the distorted pattern of the antenna array. To validate the proposed concept, a test bed with a "distorted" eight element array is set up. With the proposed calibration architecture, the estimation of the position errors is within 7% of the free space wavelength, Based on the estimation information, the array pattern can thus be synthesized**

I. INTRODUCTION

Calibration of the antenna array system has become an important part of the array system because the system performance is usually very sensitive to the phase errors. Such errors may significantly shift the direction of antenna beams and nulls, thus affect the system SNR performance [1]. Generally, the error existing in the phased array system comes from two parts- circuit error and element location error or position error. A majority of work has been done to calibrate the circuit error [2-3]. The element position error usually exists in some special communication systems called distorted phased array, such as balloon communication systems, in which the antenna array is built on the balloon's surface, with changing spacing between the elements all the time. Some

into two steps-first, an estimation algorith
estimate the position error. The basic prin
somewhat like that of GPS receivers. A s
is employed in this algorithm so that the
affect can be cancelled out. The second st
circuit error calibration.
The key technique of this system is to sep
error and circuit error with near field sou
coding technique makes it possible for th
sources to share one frequency channel.
information from the calibration system
weighting coefficients to restore the corre
pattern.
This paper is organized as follows. Sectio
basic theory of this calibration algorithm
effectiveness of the proposed approach, a
developed with an 8-element distorted an
provides the overview of such a test bed.
presents the measured results to demonstr
performance of the proposed approach. F
conclusions are made in section V.

II. CALIBRATION TI

A. Position calibration:

To calibrate the three dimensional movin
element, four sources are needed.

researchers have proposed their own calibration methods in [4-5]. however, most of those ideas are developed for certain scenarios and can not be extended for general applications. Real world phased array systems usually require a fast, simple, compact and robust calibration process.

In this paper, a self-calibration scheme for both the position error and circuit error has been presented. The essential idea is to use near field reference sources. A few advantages are associated with the proposed configuration. First, the existence of self-calibrating sources brings the calibration scheme more adaptability, even for battlefield systems in a hostile environment. Second, only very limited number the reference sources are required and these sources can be practically mounted on rigid frames. Third, the approach is insensitive to the absolute delay and phase error of the reference source, which make the approach more robust. The calibration process is divided

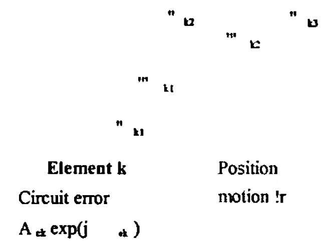


Fig.1 Geometry of array calibration

Fig.1 describes the basic idea of this posi

algorithm. The four calibration sources a
positions close to the receiving antenna a
the kth element in the smart antenna array
mechanic moving, this element has a thre

position motion r. Furthermore, there is circuit phase error $_{ck}$ in the branch k., caused by element's aging or circuit connectors and solders. $_{k\#}$, #=1,2,3,4 is the phase shift created by the distance between sources and element k. In order to make the algorithm more robust, three basic assumptions have to be made.

1) Four calibration sources are fixed in the near field of the antenna array but still far field of the each antenna.

2) Four sources are synchronized or the phase difference is known.

3) The position motion is very small compared with the distance between sources and the element.

The purpose of this algorithm is to use the phase information to calibrate the position. However, the circuit phase error $_{ck}$ does always exist in the receiving signals. Here, the phase difference between two sources' signal at the receiving element k is calculated so that $_{ck}$ is cancelled.

$$= + _k \quad (\quad _k \quad _{ck}) (\quad _{k+1} + = - _{ck}) \quad _k \quad _{k+1}$$

$$= + _k \quad (\quad _k \quad _{ck}) (\quad _{k+1} + = - _{ck}) \quad _k \quad _{k+1} \qquad (1)$$

the original position of the element can b
calibration position or virtual position. T
virtual position is that we can assume the
moving around a center point. In each tir
position motion according to the virtual p
detected so that we can "position" the ant

B. Source coding:

The four near field sources share the sam
special coding technique is needed to sep
receiving antenna. Here, orthogonal sequ
The four synchronized sources send out f
orthogonal digital signals --s1(t), s2(t), s3
These four digital signals share the same
inside one period, they satisfy:

$$\sum_{m=1}^{M} s_i(t) s_j(t) = 0$$

$$\sum_{m=1}^{M} s_i(t) s_i(t) = M$$

Hence, we can assume the total base banc
converter at the receiving antenna k becoı

Where #=1,2,3.

! $_k$ and $"' $_k$ represents the phase difference before and after motion.

Thus the circuit phase error term is removed. The next step is to construct the relationship between phase information and position motion r. Due to the assumption (3), a linear relationship can be easily found:

$$(- + _k \quad _k) \quad n_k \qquad r \; \#=1,2,3 \quad (2)$$

Obviously, the position motion is proportional to the difference of the phase difference. Here, a random phase noise term n $_k$ is added to simulate the random error in extracting the phase information from the receiving signals. Using proper DSP algorithm, such as Kalman filters, will give the best estimation of the unknowns under the noisy condition.

The reason we need four calibration sources is that the position motion is three-dimensional and at least three equations like (2) can solve for the three unknowns (!x, !y, !z).

$$\begin{matrix} x_k \\ y_k \\ z_k \end{matrix} = \mathbf{H}(x_k, y_k, z_k) \begin{matrix} - \quad k1 \quad k1 \\ - \quad k2 \quad k2 \\ - \quad k3 \quad k3 \end{matrix} \quad (3)$$

Where **H** is the coefficients matrix which is only the function of element k's original position (x $_k$,y $_k$,z $_k$) and source positions. Thus the new position of the element k can be easily obtained.

After detecting the new position of the each antenna element, the new weighting coefficients can be calculated with the adaptive beamforming technique such as sample matrix inversion (SMI).One thing needs to mention is that

$$x(n\,t=) \quad s_i(t) \; \exp(\;\;) \; A \quad R_k$$

We can use the DSP algorithm like match separate the information coming from the

$$s_m(t\,x\,n\,t)(=) \quad M \quad \exp(\quad) \quad R_k$$

$$m\,n\,j \;, \; = 1, 2,$$

Hence, the formulations (1-3) can be use position calibration.

The length of the orthogonal codes will a calibration's precision. Usually, the long give the better results. However, the long take more data collection time and DSP c The code length must be carefully selecte the moving speed of element and the requ

C. Circuit error calibration:

Circuit calibration can be realized after t calibration. Since the position error has l which means ' $_{k\#}$ and R' $_{k\#}$ are k information A $_{ck}$ exp(j $_{ck}$) can be ex (6).

$$error_k = A_{ck} \exp(j \quad _{ck})$$

Change the weighting coefficients, the pa compensated:

$$W_k' = W_k\,error_k$$

III. CIRCUIT OVERVIE

A system including one receiver and two

sources is constructed to test the technique described in section II. Assume that a mechanic motion causes the smart antenna receiver to distort from a uniform half-wavelength array to a non-uniform array. As a result, the original weighting coefficients which are calculated from the uniform array are no longer suitable to the distorted

patch array to have low mutual coupling a position motion. Each element has a 20dI a sub-harmonic I/Q mixer, which convert signals directly to IF signals. Since the sa used as the transmitter, those IF signals a band signals. An anti-parallel diode mixe

array. With the two fixed near-field sources, the element spacing error of the non-uniform array can be detected then the new weighting coefficients can be calculated to calibrate the main beam direction and null direction. The reason to use only two transmitters instead of four is that only one-dimensional motion of the antenna element needs to be calibrated.

Fig. 2 Near-field calibration sources

Fig. 3 Receiver with distorted array

Fig.2 shows the circuitry of two near-field calibration sources. Two synchronized digital sources generate 100KHz orthogonal sequences "1100" and "1010". These two digital signals are modulated with 5.828GHz synchronized LO carrier. Two transmitter antennas are quasi-Yagi antennas, which are broad bandwidth and broad beam width. Because the RF signals coming out of the mixers pass the same length of transmission line or cables then are transmitted out by the same antenna, the RF signals from the antenna can be considered as synchronized signals.

Fig.3 shows the receiver with the distorted array. The distorted array is constructed by eight compact subdivided square microstrip patch antennas, which has a size reduction of 60% compared to the conventional square microstrip patch antenna [6]. This advantage can make the

offset is designed for this system. The LO
mixer is 2dBm. In order to implement in-
quadrature-phase mixers, 45 °dela
signal path in order to achieve uniform q
signals over the RF bandwidth. As a resul
signals before low pass filter in element k
as:

$$I_i(\ ) = s_1(\ )\sin(\ +_{k1}\ \ 2\ \ _{LO}$$

$$+s_2(\ )\sin(\ +_{k1}\ \ 2\ \ _{LO}$$

$$Q_i(\ ) = s_1(\ )\cos(\ +\ \ 2$$

$$+s_2(\ )\cos(\ +_{k1}\ \ 2\ \ _{LO}$$

Notice that in (9), the amplitude informat

After low pass filter, I and Q signals ente
oscilloscope to realize the A/D converter
function. Then the sampled data are colle
transferred to PC. A matlab code works a
realize the calibration and digital beamfc

IV. MEASURED

A virtual position of each element is set t
original array is a half wavelength unifor
near field calibrated sources are fixed in (
0.156m high of the uniform array's center

Source 1

Receiver

Fig. 4 Location of the calibration sources and

Fig. 5 shows the measured base band sig
and element one of the receiver. Source o
digital signal '1100' with the amplitude 0.
two transmits '1010' with the amplitude 0
offset 0.1V. The base band I/Q signals al
offset, which will affect the precision of t
Equation (9) proposes a good way to rem
offset. From (9), in the first and last bit p
are always equal amplitude but negative s

information, the DC offset can be calculated then be removed from the I(t) and Q(t).

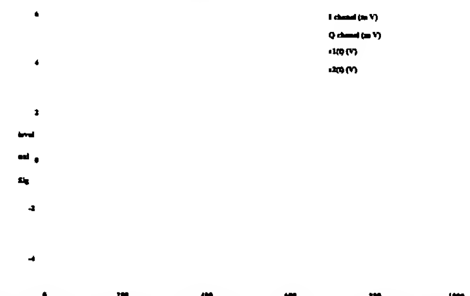


Fig. 5 Measured base band signals at the sources and receiver

(element one)

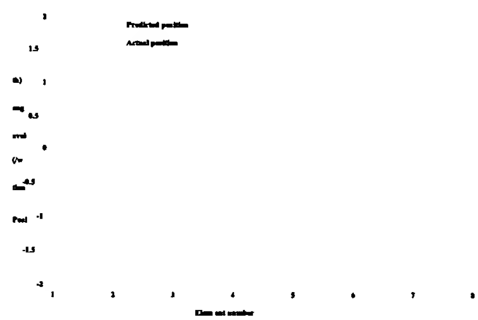


Fig.6 Predicted position and actual position of each element

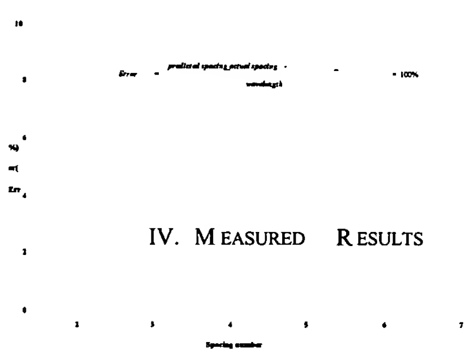
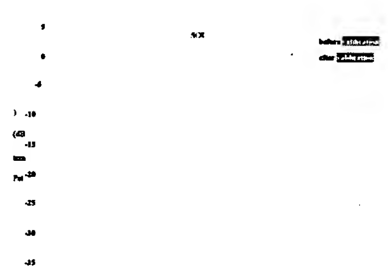


Fig. 7 Array spacing error

IV. MEASURED RESULTS



spacing, which shows our calibration alg
enough to the calibration sources' positic
Fig.7 shows the spacing error of each elei
the free space wavelength. The maximum
about 6% of the wavelength, which is too
the far field pattern. Fig.8 shows the syntl
SDMA communication, with two far fielc
and -30% respectively. Because of the ele
original pattern is highly distorted, with tl
null position shifted. After the position ca
new weighting coefficients applied, the pa

V. CONCLUSIC

A novel array calibration scheme has
a test bed has been set up to validate the c
measurement results show that it is a prec
calibration can be carried out. The spacii
is less than 7%. The distorted array patter
using the estimated element position. The
further developed to measure and calibrat
error.

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Fig. 8 Synthesized beamforming result (SOI: +30 °, SNOI: -30 °)

Fig.6 shows the predicted position and actual position of each element. A common position error exists in each element, and this error is caused by position error of the sources. However, this error will not affect the array

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